ON SOME STATISTICAL AIDS TOWARD ECONOMIC PRODUCTION

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ON SOME STATISTICAL AIDS TOWARD ECONOMIC PRODUCTION[1]

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DR. W. EDWARDS DEMING is a consultant in statistical studies, with a wide practice. He is known for his work in Japan, which created a revolution in quality and in methods of administration; Japanese manufacturers created in his honour the annual Deming Prize. Among other activities, he teaches statistical methods at New York University. He is author of several books on statistical methods, and 150 papers.

ABSTRACT. This paper covers management's responsibility for (1) design of product; (2) specification of service offered; (3) measurement by simple statistical methods of the amount of trouble with product or with service that can be ascribed to causes that only management can act on; (4) action on the causes so indicated. It shows by principle and by example how management may observe week by week the effects of guided effort toward reduction of trouble. The paper upsets a number of commonly accepted principles of administration. For example, a job-description, for best economy, should require the production-worker to achieve statistical control of his work; to meet specifications without paying the high cost of inspection, rework, and replacement. Statistical evidence of performance replaces opinion of foreman and supervisor.

As a second principle, it is demoralizing and costly to call the attention of a production-worker to a defective item when he is in a state of statistical control. The fault for the defective item is not chargeable to the worker, but to the system. Fewer defectives can come only from a change in the system, not from efforts of the production-worker.

Third, it is better to shift to a totally different job a worker that has developed statistical control of bad habits in his present job.

All variation in quality-characteristics (dimension, hardness, color) causes loss, whether the variation results in defective product or not. Economies in manufacture are a natural consequence of reduction in the variation of a quality-characteristic. The author divides causes of variation into two sources: (1) the system (common causes), the responsibility of management; (2) special causes, which are under the governance of the individual employee. In the author's experience, losses from the system overshadow losses from special causes. The same principles apply to sales and to service.

Purpose and Scope of this Paper

One purpose of this paper is to present a number of new principles of training and administration that upset generally accepted conventions. The new principles had their origin in the author's work in Japan, which commenced in 1950 [1], [2].

Another purpose is to point out to management that most of the trouble with faulty product, recalls, high cost of production and service, is chargeable to the system and hence to management. Effort to improve the performance of workers will be a disappointment until the handicap of the system is reduced.

The principles explained here will apply to any company, large or small, whether engaged in production of manufactured items or in service

[1]This paper is based on principles taught in Japan since 1950. I am indebted to the editor and to referees, and to students at New York University, for many helpful suggestions in presentation.

(hotel, hospital, restaurant, retail store, wholesale, railway, motor freight, delivery-service, communication, including the postal service), agricultural or industrial, whether owned by private investment or by the government, and in any country, whether it be developed, underdeveloped, or overdeveloped.

Many causes have contributed to devaluation of the dollar and to our precarious balance of payments, but one contributor, steadfastly avoided by economists, is that the quality of many American products is no longer competitive, here or abroad. Statisticians have failed in America to explain to people in management the impact that statistical methods could make on quality, production, marketing, labor-relations, and competitive position. Schools of business teach words and goals, but not methods.

The reader will note, I hope, that I write as a statistician, working with management on problems in industry and in research in many disciplines. I am not a consultant in management. I am not an economist.

Road-Blocks to Quality in America

An obstacle that ensures disappointment is the supposition all too prevalent that quality control is something that you install, like a new Dean, or a new carpet, or new furniture. Install it and you have it. This supposition is unfortunately force-fed by the common language of quality control engineers, some of whom offer to install a quality control system. Actually, quality control, to be successful in any company, must be a learning-process, year by year, from the top downward and from the bottom up, with accumulation of knowledge and experience, under competent tutelage.

Another road-block is management's supposition that the production-workers are responsible for all trouble: that there would be no problems in production or in service if only the workers would do their jobs in the way that they were taught. Pleasant dreams. The workers are handicapped by the system.

In my experience, it is something new and incomprehensible to a man in an executive position that management could be at fault in the production-end. Production and quality, in the view of management, are the responsibilities of the production-worker. Research into faults of the system, to be corrected by management, is not what a manager is trained for. Result: the faults of the system stay put, along with rejections and high costs of production.

Management usually discharges its responsibilities (sweeps them under the rug) by turning the job over to a department of quality control. This would be a happy solution and good administration if it solved anything, but it seldom does: the job lands on people that try hard but have not the necessary competence, and the management never knows the difference.

As a result, one finds in most companies not quality control, but guerrilla sniping—no provision nor appreciation for the statistical control of quality in the broad sense of this paper.

People in management need to know enough about quality control to be able to judge whether their quality control departments are doing the job.

Statements by management of aims desired in quality and production are not quality control, nor are they action on improvement of the system. Neither are periodic reviews and evaluations of quality and production. They are necessary but not sufficient.

Exhortations, pleas, and platitudes addressed to the rank and file in an organization are not very effective instruments for the improvement of quality. Something more is required.

I should mention here also the costly fallacy held by many people in management that a technical man (a statistician, for example) must know all about a process and all about the business in order to work in the company. All evidence points to the contrary. Competent men in every position, from top management to the humblest worker, if they are doing their best, know all there is to know about their work *except how to improve it*. Help toward improvement can come *only from some other kind of knowledge*. Help may come from outside the company, or from better use of knowledge and skills already within the company, or both.

Loss from Variation. Two Sources of Variation

It is good management to reduce the variation of any quality-characteristic (thickness, or measure of performance), whether this characteristic be in a state of control or not, and even when no or few defectives are produced. Reduction in variation means greater uniformity and dependability of product, greater output per hour, greater output per unit of raw material, and better competitive position [5], [7].

Causes of variation and of high cost, with loss of competitive position, may be usefully subsumed under two categories:

Faults of the system *(common or environmental causes)*	*Special causes*
85%	15%
These faults stay in the system until reduced by management. Their combined effect is usually easy to measure. Some individual causes must be isolated by judgment. Others may be identified by experiment: some by records on operations and materials suspected of being offenders (see reference to Juran).	These causes are specific to a certain worker or to a machine. A statistical signal detects the existence of a special cause, which the worker can usually identify and correct.

Both types of cause require attention of management. Common causes get their name from the fact that they are common to a whole group of workers: they belong to the system [2].

No improvement of the system, nor any reduction of special causes of variation and trouble, will take place unless management attacks common causes with as much science and vigor as the production-workers and engineers attack special causes [3].

The percentages shown, are intended only to indicate that, in my experience, problems of the system overshadow special causes. The percentages will fluctuate as special causes are eliminated one by one, and as faults of the system are reduced or eliminated.

Confusion between the two types of cause leads to frustration at all levels, and leads to greater variability and to higher costs—exactly contrary to what is needed.

Fortunately, this confusion can be eliminated with almost unerring accuracy. Simple statistical techniques, distributions, run-charts, Shewhart control-charts, all explained in many books, provide signals that tell the operator when to take action to improve the uniformity of his work. They also tell him when to leave it alone. Results of inspection, without signals, lead to frustration and dissatisfaction of any conscientious worker.

What is not in the books, nor known generally amongst quality-control engineers, is that the same charts that send statistical signals to the production-worker also indicate the totality of fault that belongs to the system itself, correction of which is management's responsibility [2]. The production-worker can observe from his charts whether attempts by management to improve the system have had an effect. Management can give themselves the same test. Examples appear further on.

Removal of a special cause of variation, important though it be, is not improvement of the system: it merely reduces the variation to a level that identifies the system, but leaves it unimproved.

Mechanical feed-backs that hold dimensions and other quality-characteristics within bounds are sometimes helpful but may be wasteful of material and of machine-time. They do not improve the system. Better understanding of the function of feed-back systems, so as to use them effectively, and to supplement them, will be an important step for management.

"We rely on our experience," is the answer that came from the manager of quality in a large company recently, when I inquired how he distinguishes between the two kinds of trouble, and on what principles. This answer is self-incriminating: it is a guarantee that this company will continue to pile up about the same amount of trouble as in the past. Why should it change?

"Bill," I asked of the manager of a large company engaged in motor-freight, "how much of this trouble (shortage and damage, 7911 examples in one terminal alone in 1974) is the fault of the drivers?" His reply, "All of it," is again a guarantee that this level of loss will continue until statistical methods detect some of the sources of trouble with the system for Bill to work on.

The QC-Circle movement in Japan (3 million members; 4 to 8 workers to a circle) gives to production-workers the chance to study and revise the system of production at the local level, for greater output and better quality. Japanese workers are not handicapped by the rigidity of the American production-line. The QC-Circles represent partial decentralization of management's responsibility to find local faults in the system, and to take action on them. The QC-Circles in Japan bear no relationship to suggestion-boxes, common everywhere.

The boost in morale of the production-worker, if he were to perceive a genuine attempt on the part of management to improve the system and to hold the production-worker responsible only for what the production-worker is responsible for and can govern, and not for handicaps placed on him by the system, would be hard to overestimate. It has not been tried, I believe, outside Japan.

It is now clear that the term zero defects can only be a theatrical catchword, a nostrum. The management of many concerns have adopted it outright or in equivalent form and have posted it all over the plant for everyone to see, especially visitors, expecting magic. Empty words they are till the management acknowledges responsibility toward reduction of common causes. One company that I know of reduced their defects by eliminating 8 inspectors out of 10. This is a successful approach until the defectives start coming back with claims attached.

Thumb-Nail Sketch of the State of Statistical Control

Some understanding of the concept of statistical control, invented by Shewhart [6] is necessary as background. A state of statistical control is a state of randomness. Simple tests of randomness are the Shewhart charts—run charts, $\bar{x}$-charts, R-charts. The up and down movements on a chart are to be disregarded by the production-worker unless there is indication of a special cause. A point that falls outside the control limits is a statistical signal that indicates the existence of a special cause of variation. This the production-worker can almost always identify readily and correct.

Control limits are not specification limits. Control limits are set by simple statistical calculations from the output itself. What the control limits do is to send out signals that if heeded will minimize the net loss from the two kinds of mistakes that the production-worker can make:

1. Adjust the machine or his work when it would be better to leave it alone.
2. Fail to adjust the machine or his work when it needs adjustment.
   The only rational and economic guide to minimum loss is statistical signals.

The production-worker himself may in most cases plot the statistical charts that will tell him whether and when to take action on his work. He requires only a knowledge of simple arithmetic. But the production-worker cannot by himself start his own chart, and still less a movement for use of charts. Management must start the movement, and stay on the job.

Some processes in nature exhibit statistical control. Radio-active disintegration is an example. The distribution of time to failure of vacuum tubes and of many other pieces of complex apparatus furnish further examples. But a state of statistical control is not a natural state for a manufacturing process. It is instead an achievement, arrived at by elimination one by one, by determined effort, of special causes of excessive variation.

Figure 1 shows the results of inspection from a process that is not in stastical control. The upper panel $(\bar{x})$ average of 5 successive items indicates the existence of special causes. There are points below the lower control limit and too many points on the border of the upper control limit. The lower panel (range (R) shows a downward trend, which, although it may indeed be a trend toward greater uniformity, indicates nevertheless also the existence of one or more (possibly additional) special causes, which again the worker must discover and correct. The charts thus indicate the existence of special causes, elimination or reduction of which is the responsibility of the operator. The reader may turn to Figures 2 and 4 to see a state of statistical control.

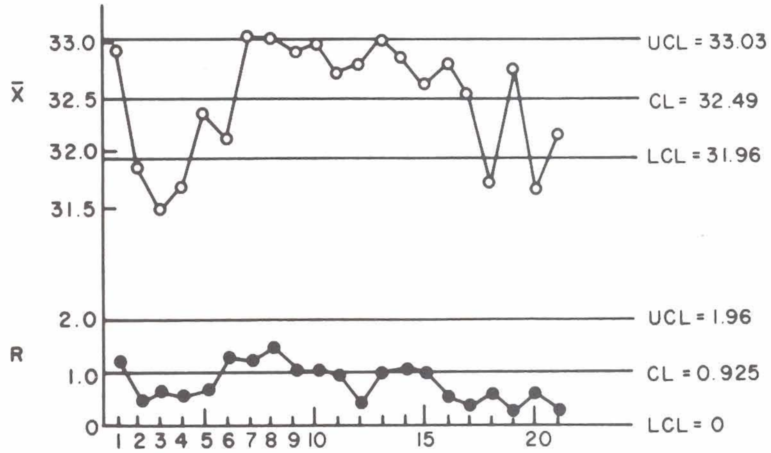

FIGURE 1. A control chart, showing the existence of special causes of variation. Taken from W. Edwards Deming, *Elementary Principles of the Statistical Control of Quality* (Union of Japanese Scientists and Engineers, Tokyo, 1950), p. 31.

A process has an identity only if it is in a state of statistical control. The control limits, and the size of the sample, then enable the manufacturer to predict rationally the level and range of variation of product that will come off the line tomorrow. The same principles and rules are applicable to service-organizations.

Statistical control thus provides a basis for doing business in a rational way. The manufacturer knows what quality he can produce, and at what cost. He will not walk into heavy loss by taking a contract for uniformity that he cannot meet, or can meet only by inspection and rework, always costly and unsatisfactory. He can make no rational prediction about his product and costs when his processes are not in statistical control.

Results of inspection are too often unreliable—worse, are sources of strife —because of mistrust of the measurements whether made by use of instruments or by visual inspection. Measurement must be viewed as a process, the product of which is figures. A method of measurement cannot be dignified as a method, unless, with some operators at least, it shows a state of statistical control. A control chart is a powerful scientific tool.

The first step in many plants is to achieve reasonably good statistical control of some of the main operations, including inspection. The next step is for management to work on the common causes of variation and of defective products.

Textbooks on quality control (except for Juran [3]) teach only detection of special causes (Shewhart's assignable causes) and acceptance sampling (for disposition of product already on hand). These are important statistical methods, but acceptance sampling does not build quality that is not already there; and removal of special causes stops short of the main part of the problem, namely, faults of the system.

The explanation is simple. The usual terminology, following Shewhart [6] himself, is that the remaining sources of variation, lumped together, once control is established, constitute "chance causes," variation to leave to chance. This is the correct view for the production-worker in a state of control: he should indeed leave the remaining variation to chance. Likewise for a group of workers, or a line, or a process: ups and downs in a state of control are not a basis for action on the process.

The contribution that I am trying to make here is that management must take a different view: management *must not* leave the remaining variation to chance.

Familiar Consequences of Faults of the System

Recalls of automobiles, electrical apparatus, and of other items, familiar enough to people in America, for possible hazards from failure of components and assemblies, or from contamination, are signs of faults in design. Failure to carry out adequate tests of components and assemblies over the ranges of jolt, stress, dust, speeds, voltages, corrosion, likely to be met in practice, or failure to heed the results of such tests, is chargeable to the system; hence to management. Or, as sometimes happens, management sometimes goes ahead with production, test or no test, to beat a competitor to the market-place. No amount of care and skill on the part of the production-worker can overcome a fault in design. Where is the statistician's report on the performance of parts and assemblies that give rise to trouble and to recalls?

If one enquires whether more experimentation in advance would have overpaid its cost, or whether it is better business to rush into the market-place and take a chance, I would offer the following remarks: (a) no dollar-value can be placed on the unhappiness of a customer and the loss of future business over a defective item of an unsatisfactory service-call; (b) the costliest experimentation on the performance of a product is the tests the customer caries out for himself. (c) cost-benefit analysis has important uses, but also serious limitations. If the Japanese manufacturers had depended on cost-benefit analysis in 1949 to decide whether to learn and use the statistical control of quality, they would, I surmise, have given it a negative vote, or would still be studying the matter.

Partial List of Usual Faults of the System
(Common or Environmental Causes of Variation)

The reader may make additions and subtractions to suit his own situation.

1. Hasty design of component parts and assemblies. Inadequate tests of prototypes. Hasty production.
2. Inadequate testing of incoming materials. Specifications that are too stringent, or too loose, or meaningless. Waiving specifications.
3. Failure to know the capabilities of processes that are in a state of statistical control, and to use this information as a basis for contracts, both for quantity and quality.
4. Failure to provide production-workers with statistical signals that will tell them how they are doing and when to make some change.
5. Failure to use these charts as a measure of the faults of the system, and of the effect of action taken by management to reduce them.
6. Failure to write job-descriptions that take account of the capability of the process.
7. Inadequate training of workers, with the help of statistical controls.
8. Settings of machines chronically inaccurate (fault of the crew responsible for settings).
9. Instruments and tests not reliable. Consequent demoralization and loss from false reports and false signals. Loss from needless retesting.
10. Smoke, noise, unnecessary dirt, poor light, humidity confusion.

The production-worker is helpless to reduce any of these causes of trouble. Economic considerations must of course govern the decision of management to reduce or eliminate a fault of the system. An easy way out is to say that it would cost too much.

A Word on Due Care

Statistical control and its consequences, if explained by statisticians to the legal profession in industry and in government, would clear up many problems about safety and reliability. The most that a manufacturer can put into the uniformity and dependability of a device is (a) to achieve and maintain statistical control, at the right level and spread, of the most important quality-characteristic of the main outgoing components and assemblies, and incoming ingredients, and (b) to be able to demonstrate by adequate statistical records and charts, along with action taken on special causes and on common causes, that he has done so.

In spite of scrupulous care and intelligent use of statistical controls, it is inevitable that a defective item will get out now and then. An unfortunate freak of this kind cannot be viewed as an act of carelessness on the part of the manufacturer. He can do no more than to exercise due care.

Some New Principles in Administration

This paper upsets some well-accepted principles of administration, which when examined under the logic of statistical inference turn out to be bad practice—that is, demoralizing to the rank and file of production-workers, and costly. For example, it turns out to be bad practice to draw the attention of a production-worker to a defect in his work when he is in a state of statistical control. Why? The production-worker is helpless: he cannot do better. It is as if he were drawing blindfolded handfuls from a mixture of black and white beans. The number of black beans in a handful may be 0, or it may be 1, or 2, or more. The laws of chance apply. He cannot alter these laws, once he achieves statistical control. He will only make things worse (increase the proportion of black beans) if he tries to adjust his work except on statistical signal. To draw his attention to an error or to hold him on the job until he corrects it is to charge him with a fault of the system.

Yet it is common practice in industry, whether it be production or service, to bring to the attention of a man any output that is discovered to be defective. In an example that I could cite, a production-worker, whether in a state of statistical control or not, reworks on his own time, all the defectives that inspection discovered in the product that he turned out during his shift. This is what some people call quality control. The reason given to me upon enquiry is that this procedure is a continual reminder to the production-worker that defectives will not be tolerated; that he is responsible for the work that he turns out. How can he improve if he doesn't know about his mistakes?

Like so many obvious solutions to problems, this one is also wrong. The fallacy in this principle is demonstrated by dependable day-to-day figures on rejections.

A job-description, for best economy, should require achievement of statistical control of a dimension [4]. Under this requirement, the production-worker is in charge of his own process, and can achieve in his work maximum economic uniformity and output. This is very different from asking a production-worker to force a dimension of individual pieces to stay within specified limits.

An economic level and spread of the control limits would produce a distribution for individual pieces that rarely if ever extends beyond the specification and produces a defective item. It is the responsibility of the foreman or higher supervision to remove obstacles to an economic level and spread. This might mean better setting of the machine, or better maintenance, or incoming materials better suited to the right spread. None of this refinement in job-descriptions will take place without understanding and action on the part of management (see Example 1).

A state of statistical control can exist in a climate of mild but uniform carelessness. This degree of carelessness is part of the system, the climate. In my experience, workers seldom know the cost of carelessness nor the cost of a mistake (see Example 2). Only management can teach them.

To call to the attention of a worker to a careless act, in a climate of general carelessness, is a waste of time and can only generate hard feelings, because the condition of general carelessness belongs to everybody and is the fault of management, not of any one worker, nor of all workers.

A general reminder, posted in a factory so that everyone can see it, to explain to the workers the cost of a defective item, or the cost of a mistake, may be helpful in improving the system. Meetings illustrated with moving pictures to show how defects are made, caught in the act, are also helpful.

Continuing education on the job to rehearse principles of the job and the cost of defective work belong in the system. This is management's job: workers cannot institute it.

A worker who is in a state of control but whose work is unsatisfactory presents a difficult problem. It is usually uneconomical to try to retrain him on this same job. It is more economical to put him into a new job in which the training may be more expert than it was in his present job.

Figure 2 provides an illustration. An experienced man in golf hoped to improve his score by taking lessons. The chart shows that the lessons accomplished nothing. His techniques were engrained: his teacher was unsuccessful in dislodging them and replacing them with better ones.

Curiously, so long as a man has not reached a state of statistical control, there is hope. Figure 3 shows average scores $(\bar{x})$ in golf for a beginner. His scores, before the lessons, were obviously not in a state of control: there are points outside the control limits. Then came lessons. His scores thereupon showed a state of statistical control with the desired results, viz., an average score considerably below what his average was before the lessons. Here, lessons changed the system.

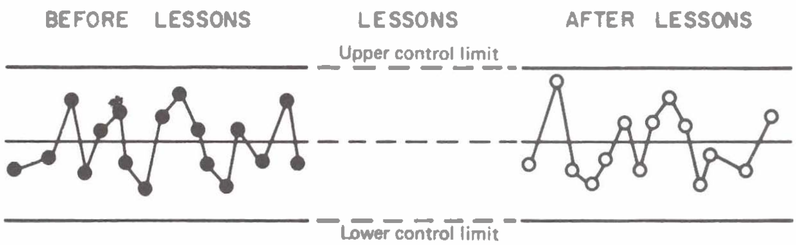

FIGURE 2. Average scores in golf for an experienced golfer, before and after lessons. Taken from W. Edwards Deming, *Elementary Principles of the Statistical Control of Quality* (Union of Japanese Scientists and Engineers, Tokyo, 1950), p. 22.

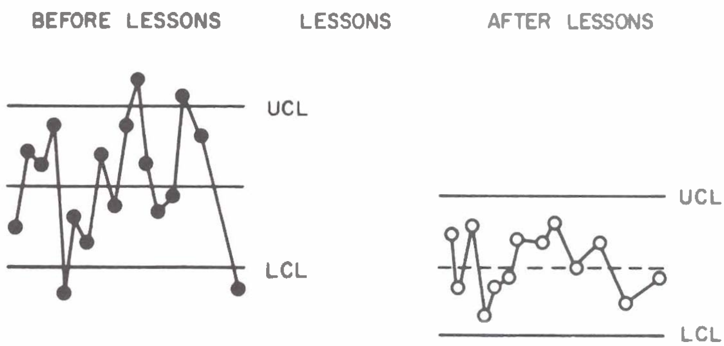

FIGURE 3. Average weekly scores in golf for a beginner who took lessons before he reached a state of statistical control. Taken from the book cited in Figure 2.

Ten production-workers may all be in statistical control as individuals, all at different levels. Their combined output will also be in control. *Improvement comes about by studying the individual workers, transferring to another job with a fresh start anyone that is out of line on the side of poor performance.*

It is my observation that training in industry is deplorable. A new employee simply goes to work. Written instructions for the job, if they exist, are in many cases incomprehensible. What happens is that the new worker gives up on the instructions for fear of being further confused. His co-workers come to the rescue, instructions or no instructions, and in a few days he is running along with the herd. The service industries (restaurants, hotels, laundries, etc.) provide horrible examples. The argument is that instruction and training are too costly, and that it is all lost if an employee quits the job.

In contrast, a girl that runs a lift in Japan, or is conductor on a bus, spends two months in training on how to handle people, this in spite of her genteel background of culture.

Training or the lack of it is part of the system. Training can be improved only by management, certainly not by the workers.

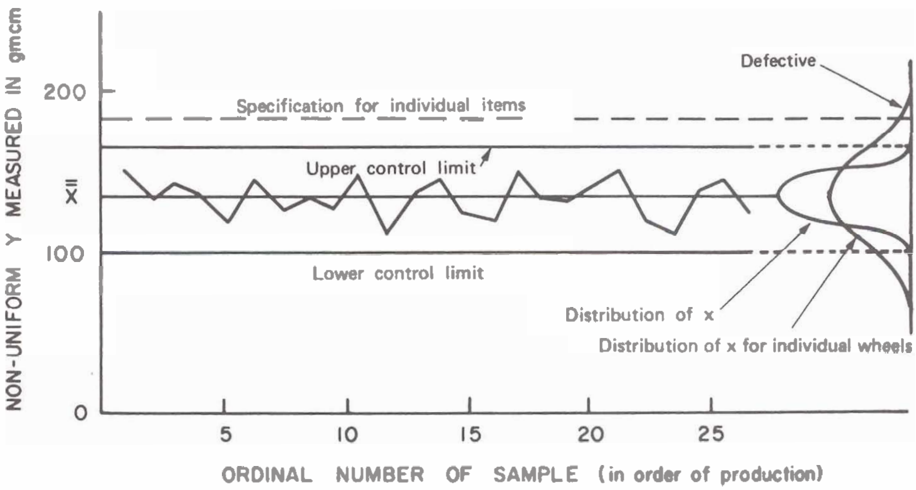

FIGURE 4. Chart for $\bar{x}$ for test of uniformity of wheels turned out by a production-worker.

Example 1.

This example illustrates how a small change in the system could virtually eliminate the possibility of defective items. The ordinates in Figure 4 are the means ($\bar{x}$) of samples of $n = 3$ for tests of uniformity of finished wheels. The test is the running balance of the wheel. Observations:

1. The production-worker is in a state of control with respect to his own work (which is the only work that he is responsible for). No point falls outside the control limits.
2. He is under the handicap of the system. He cannot beat the system and the capability of his process: he will once in a while produce a defective wheel, even though he is a good worker and in a state of control.
3. He is meeting the requirements of his job. He can do no more. He has nothing further to offer.

4. The main trouble lies in the system. The central line in Figure 4, which fall at about 125 gram-cms, represents the contribution of the system to the total trouble. This handicap is built in. If the faults of the system were reduced to 75% of their present level, the upper tail of the distribution of individual pieces would drop well below the specification limit, and the entire production would be accepted; economies in production would be realized.

The reaction of management on the above paragraphs was the usual one, namely, that they did not have in mind this kind of quality control when they went into it. They were looking for everything to clear up, once the production-workers put their best efforts into the job. Eventually, however, patience paid off.

Charts like Figure 4 are to be seen almost anywhere, but interpretation of them in terms of a quantitative measure of the faults of the system are rare.

Example 2.

The second example deals with a service-industry, motor freight. Drivers of trucks pick up shipments and bring them into a terminal for reload and onward movement. Other drivers deliver. A large company in motor freight may have anywhere from ten to forty terminals in or near large cities. There is a long chain of operations between the request of a shipper to the carrier (usually by telephone) to come and pick up a shipment, and placement of the shipment on the platform of the carrier, ready for reload and line-haul to the terminal that serves the destination of the shipment. Every operation offers a chance for the driver to make a mistake. The table shows 6 types of mistakes, plus all others. Although the frequency of mistakes is low, the total loss is substantial.

In mistake No. 1, the driver signs the shipping-order for (e.g.) 10 cartons, but someone else finds, later on in the chain of operations, that there are only 9 cartons; one carton missing. Where is it? There may have been only 9 cartons in the first place; the shipping-order was written incorrectly; or, more usual, the driver left one carton on the shipper's premises. Let us list some of the sources of loss from mistake No. 1:

1. It costs about $25 to search the platform for the missing carton, or to find the truck (by now out on the road) and to search it.
2. It costs $15 on the average to send a driver back to the shipper to pick up the missing carton.
3. It costs $10 to segregate and hold the 9 cartons for the duration of the search.
4. If the carrier does not find the carton, then the shipper may legitimately put in a claim for it. The carrier is responsible for the 10th carton. Its value may be anywhere from $10 to $1,000, with the possibility of an amount even greater.

It is obvious that Mistake No. 1 may be costly. Any one of the 7 mistakes will on the average lead to a loss of $50. There were a total of 617 mistakes on the record, and they caused a loss of $31,000 for claims alone. Multiplied by 20, for 20 terminals, the total loss from the 7 mistakes was $620,000. (This amount is a minimum. It does not include the expenses of searches nor administration. Moreover, some mistakes are not included in the total of 617, but they nevertheless cause loss.)

The 7 types of mistake

Type of mistake	Description
1	Short on pick up
2	Over on pick up
3	Failure to call in (by telephone) on over, short, and damaged cartons on delivery
4	Incomplete bill of lading
5	Improperly marked cartons
6	Incomplete signature on delivery-receipt
7	Other

There were 150 drivers that worked all year long. Figure 5 shows the distribution of the 150 drivers by number of mistakes, all 7 mistakes combined.

We postulate the following mechanism, which will distribute errors at random to drivers. We imagine a huge bowl of black and white beads, thoroughly mixed. Each driver scoops up a sample of 1,000 or more (the number of trips that an average driver makes in a year), and returns the beads to the bowl for more mixing. The number of black beads in a scoop will be a random variable, following the Poisson distribution. The total number of mistakes in Figure 5 is 617, and there were 150 drivers. An estimate of the mean number of mistakes per driver would be

$$\bar{x} = 617/150 = 4.1 \tag{1}$$

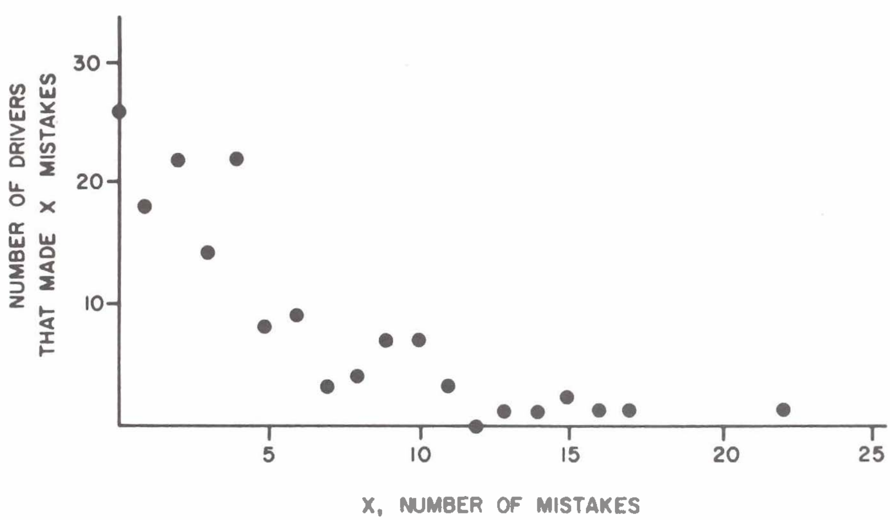

FIGURE 5. The distribution of drivers by number of mistakes, all 7 errors combined.

The upper and lower 3-sigma limits for these samples would be easy to calculate by use of the square-root-transformation, by which

$$(\sqrt{4.1} + 1.5)^2 = 12 \qquad \text{[upper limit]} \tag{2}$$

and

$$(\sqrt{4.1} - 1.5)^2 = 0 \qquad \text{[lower limit]} \tag{3}$$

One may perform the same calculations instantly by use of the Mosteller-Tukey double square-root paper [8].

We interpret the upper limit to mean that a driver that made 12 or more mistakes in the year is not part of the system. He contributes more than his share. He is a special cause of loss. I may add here that other statistical models that I have tried lead to about the same conclusions.

Drivers that made 0, 1, 2, 3, or 4 mistakes are far more numerous than the Poisson distribution would allow. I accordingly consolidate the drivers that made 0, 1, 2, 3, or 4 mistakes, and postulate that they too form a separate group. There are then three groups of drivers:

A. Drivers that made 12 or more mistakes.
B. Drivers that made between 5 and 11 mistakes.
C. The extra careful group, drivers that made 0, 1, 2, 3, or 4 mistakes.

What have we learned from this simple statistical model?

1. The 7 drivers with 12 or more mistakes accounted for 112/617 or 18% of the mistakes. They could reduce their rates of mistakes to average if they knew that they were outliers.

2. Drivers that made 5 to 11 mistakes measure the losses that arise from the system itself. They make the system what it is. They account for (425 - 112)/617 or about 51% of the mistakes. Clearly, about half the losses from the 7 types of mistake arise from the system as it is.

3. The 102 drivers of Group C accounted for only 192/617 = 31% of the mistakes. This Group C is worth studying: how do they do it? Did they have easy routes or easy conditions (e.g., day-time pick-ups, inside pick-ups), or do they have a system of their own? These are questions to pursue. If these men have a system of their own, then they should teach the others. (Enquiry turned up no evidence of easy routes.)

No problem with people is simple. It would be wise for the management to defer criticism of Group A, to determine first whether these drivers worked unusually difficult routes, or whether they had achieved excessive mileage (high productivity). As it turned out, they had.

Here we encounter an important lesson in administration. This company had been sending a letter to a driver at every mistake. It made no difference whether this was the one mistake of the year for this driver, or the 15th: the letter was exactly the same. A letter sent to a driver in Group B or C is demoralizing: the driver's interpretation thereof—and he is absolutely correct—is that he is blamed for faults of the system.

The management had failed to see that they face three distinct types of problem. What was needed was a separation of responsibilities for improvement—special causes, to be corrected by the drivers of Group A; the system itself, to be improved by the management; study of Group C; and examination of the accuracy of their records of mistakes.

One might pause here in passing to ask two questions: (1) what does the manager of the terminal think of the driver to whom he has sent in one year 15 warnings of disciplinary action? More important, (2) what does the driver think of the manager?

Example 3.

A small manufacturer of shoes was having trouble with his sewing machines, rent of which was very costly. The operators were spending a lot of their time rethreading the machines, a serious loss.

The key observation was that the trouble was common to all machines and to all operators. The obvious conclusion was that the trouble, whatever it was, was common, environmental, affecting all machines and all operators. A few tests showed that it was the thread that caused the trouble. The owner of the shop had been purchasing poor thread at bargain prices. The loss of machine-time had cost him hundreds of times the difference between good thread and what he had been buying. Bargain prices for thread turned out to be a costly snare.

Better thread eliminated the problem. Only the management could make the change. The operators could not go out and buy better thread, even if they had known where the trouble lay. They work in the system. The thread was part of the system.

Prior to the simple investigation that found the cause, pedestrian but effective, the owner had supposed that his troubles all came from inexperience and carelessness of the operators.

Example 4.

The work of every one of 50 production-workers on a certain production-line is in statistical control. The manager of personnel came forth with a plan, immediately hailed by the management, to award monthly a prize and half a day off to the operator on this line whose production the month before showed the smallest proportion of defective product.

Was this a good idea? What was wrong? Why should the statistician advise the management to drop the idea? The answer is that it would not improve the performance of the workers, nor improve quality.

Why not? Every operator has already put into the job all that he has to offer: the work of each one is in a state of control.

This award would not be an award of merit. What harm would come from it? It would produce frustration and dissatisfaction amongst conscientious workers. Their efforts to find out what they are doing that is wrong, and why their work is not as good as that of the man that won the prize, would be a fruitless chase. They would try out changes in their operations, the only effect of which would be greater variability, not less.

The award would be a lottery. There would be no harm that I know of in introducing a lottery for excitement, provided management calls it a lottery, not an award of merit.

This is an example of administration without statistical judgment. The plan seemed to be a great idea until examined by the theory of probability, with reference to special causes and common causes.

What the personnel-man could do, if he wishes to offer a prize and be effective, is to reward a man that contrives ways to improve the system, to decrease the per cent defective for the group by some stated amount of economic importance.

Management could make good use of the figures on defectives for the 50 workers, but not to award a prize. The 50 proportions of defectives furnish a basis, by use of the simple statistical technique called chart for fraction defective, to discover which worker if any ought to be transferred and trained in other jobs. The same chart, even if the 50 workers were not in statistical control with each other, would indicate how much of the overall fraction defective arises from the system itself, beyond reach of the workers, and correctible only by management.

Concluding Remarks

The principles expounded here, and the examples of application, are all simple, yet the economic gains from corrective action by management are considerable. The examples all belong to the statistical control of quality. Did the solutions require a statistician? Couldn't other people have done as well? One answer is that other people had their chance.

Some people would call this work operations research. Some would call it systems-analysis: others, industrial engineering. To me, it is just a statistician trying to be positive and helpful in the use of statistical methods.

When will schools of busines and other academic departments get into the business of teaching modern principles of administration and mangement? Without statistical logic, management learns words and goals, but not methods by which to reach these goals, nor meaningful language by which to describe a goal or to measure advancement toward it or away from it.

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